The Film Cap. Tech. For DC Link

Xiamen Faratronic Co. Ltd.
201912
APEC Booth 1156
Anvy Chen
Deputy manager of R&D department
Xiamen Faratronic CO., LTD.
Senior engineer
focus on development of DC-Link film capacitor
More than 12 years.

Address: No.99 Xinyuan Road, Xiamen, China.
Postcode: 361022
Tel: 86 592 2338263
Fax: 86 592 6208550
E-Mail: cyw@faratronic.com.cn
Agenda:

- Capacity introduction and main customers
- The film capacitors technology for DC link
- Reliability test and performance
- Roadmap and Development strategy
Capacity (DC-Link caps for automotive)

- Factory location: HQ
- Current Capacity: 45 kpcs/month
- Production Layout: Station

- Factory: New DC-Link caps factory
- Current Capacity: 80 kpcs /month
  - Line 1: 20 kpcs / month
  - Line 2: 30kpcs / month
  - Line 3: 30kpcs / month
- Planning: Line 4: 30kpcs / month
- Production Layout: Automation Line (Connection from Soldering Process -- Packing Process)

**DC-Link Capacitors’ Selling Q’ty in year 2019: 600kpcs**
Marketing Segment for Automotive Market

• 30% European Market
• 70% Domestic Market

Main Customer

- Bosch
- Continental
- ZF
- Valeo
- Zollner
- UAES
- NIO
- BYD
- EDrive
- Inovance
The film capacitors technology for DC link

- DC link capacitor becomes one of the key components in the inverter of EV/HEV.

Old solution: Electrolytic capacitors

Current solution: Film capacitor
Properties of polypropylene film compare with electrolytic capacitor

- Capacitance is stable in operation temperature and frequency

  **PP-film capacitor**
  - Capacitance drift ≤ 5% (-40°C ~ 100°C)

  **Aluminum electrolytic capacitor**
  - Capacitance is stable (100Hz ~ 100 KHz)

- High voltage proof ability
- Low ESR, high ripple current handling ability
- Low ESL
- Long lifetime
- Customize design
Properties of polypropylene film compare with other dielectric film materials

**Advantage:**
- Low losses;
- Small volume;
- High voltage proof ability;
- Excellent self-healing property
- Good stability;
- Low cost

**Disadvantage:**
- Operation temperature lower than 115°C

<table>
<thead>
<tr>
<th>Properties</th>
<th>PP</th>
<th>PET</th>
<th>PEN</th>
<th>PPS</th>
<th>PTFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>High temp.</td>
<td>No so good</td>
<td>General</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Low losses</td>
<td>Excellent</td>
<td>No so good</td>
<td>No so good</td>
<td>General</td>
<td>Excellent</td>
</tr>
<tr>
<td>Volume</td>
<td>General</td>
<td>General</td>
<td>General</td>
<td>No so good</td>
<td>Bad</td>
</tr>
<tr>
<td>High-voltage</td>
<td>Excellent</td>
<td>General</td>
<td>General</td>
<td>Bad</td>
<td>General</td>
</tr>
<tr>
<td>Stability</td>
<td>General</td>
<td>No so good</td>
<td>General</td>
<td>General</td>
<td>Excellent</td>
</tr>
<tr>
<td>Price</td>
<td>Excellent</td>
<td>General</td>
<td>Bad</td>
<td>Bad</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Break down voltage of PP film

Good Self-healing point

Bad Self-healing point
• Typical structure and features

Housing:
Excellent humidity and mechanical performance

Epoxy:
Excellent humidity performance;
Excellent temperature performance;

Capacitor element:
Low ESL & ESR;
Special segmented film design;
Heavy-edge technology;
Wave-cutting technology

Busbar:
Low ESL & ESR;
Easy assembly
Reliability test and performance

- Test condition reference

1) AECQ 200D

2) ZVEI-Qualification_KFZ-DC-Link-Capacitors
• Main reliability test and performance

**Operational life test**

Test condition: Rated voltage, Maximum operation temperature, 2500 hours

Failure mode: Capacitance loss & ESR increasing

Causes: Material aging, oxidation of metal, plastic parts performance at maximum temp., internal connection.

Typical test case:

![Capacitance loss](image)

![ESR increasing](image)
Temperature cycling test

Test condition: 60min./60min. TH to TL, rapid change, T < 1min.
Failure mode: Crack, Capacitance loss, ESR increasing
Causes: Material aging, oxidation of metal, internal connection, internal mechanical stress variation.

Typical test case:

![Graphs showing Capacitance loss and ESR increasing over cycles](image-url)
Bias humidity test

Test condition: Rated voltage, 65°C, 93% RH, 1750 hours

Failure mode: Capacitance loss, ESR increasing

Causes: Humidity resistance ability of material, oxidation of metal, internal connection

Typical test case:

**Capacitance loss**

<table>
<thead>
<tr>
<th></th>
<th>0h</th>
<th>500h</th>
<th>1000h</th>
<th>1500h</th>
<th>1750h</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Y0991196</td>
<td>0</td>
<td>-0.14%</td>
<td>-0.12%</td>
<td>-0.14%</td>
<td>-0.48%</td>
</tr>
<tr>
<td>2Y0991206</td>
<td>0</td>
<td>-0.12%</td>
<td>-0.04%</td>
<td>-0.12%</td>
<td>-0.11%</td>
</tr>
<tr>
<td>2Y0991199</td>
<td>0</td>
<td>-0.11%</td>
<td>-0.11%</td>
<td>-0.12%</td>
<td>-0.21%</td>
</tr>
<tr>
<td>2Y0991202</td>
<td>0</td>
<td>-0.12%</td>
<td>-0.11%</td>
<td>-0.12%</td>
<td>-0.15%</td>
</tr>
<tr>
<td>2Y0991211</td>
<td>0</td>
<td>-0.13%</td>
<td>-0.11%</td>
<td>-0.12%</td>
<td>-0.30%</td>
</tr>
<tr>
<td>2Y0991214</td>
<td>0</td>
<td>-0.12%</td>
<td>-0.11%</td>
<td>-0.13%</td>
<td>-0.43%</td>
</tr>
</tbody>
</table>

**ESR increasing**

<table>
<thead>
<tr>
<th></th>
<th>0h</th>
<th>500h</th>
<th>1000h</th>
<th>1500h</th>
<th>1750h</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Y0991196</td>
<td>0</td>
<td>3.57%</td>
<td>3.57%</td>
<td>3.57%</td>
<td>3.57%</td>
</tr>
<tr>
<td>2Y0991206</td>
<td>0</td>
<td>0.00%</td>
<td>-3.45%</td>
<td>-3.45%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2Y0991199</td>
<td>0</td>
<td>-3.45%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>3.45%</td>
</tr>
<tr>
<td>2Y0991202</td>
<td>0</td>
<td>3.57%</td>
<td>3.57%</td>
<td>0.00%</td>
<td>3.57%</td>
</tr>
<tr>
<td>2Y0991211</td>
<td>0</td>
<td>0.00%</td>
<td>-3.45%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>2Y0991214</td>
<td>0</td>
<td>-3.45%</td>
<td>0.00%</td>
<td>-3.45%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
According to the market requirements, development tendency of DC link film capacitor should be:

- Smaller volume
- Higher temp.
- Light weight
- Higher ripple current handling
- Higher frequency application

### Roadmap and Development strategy

**Roadmap for PP film DC Link capacitor**

<table>
<thead>
<tr>
<th>Target</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage/μm</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>≤115°C</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>Max.: 224V/μm</td>
<td>≤115°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max.: 237V/μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max.: 265V/μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max.: 310V/μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Target: Smaller volume and light weight!
• Development works for PP film capacitor
  - PP film optimization (work with raw material supplier)
  - Metallization process optimization
  - Capacitor manufacture process optimization
  - Lifetime study for design optimization

Typical lifetime curves:

Energy density change of Faratronic’s film capacitor

<table>
<thead>
<tr>
<th>Energy density (Q × AJ/ml)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Q</td>
<td>2009</td>
</tr>
<tr>
<td>1.11 Q</td>
<td>2011</td>
</tr>
<tr>
<td>1.32 Q</td>
<td>2014</td>
</tr>
<tr>
<td>1.57 Q</td>
<td>2017</td>
</tr>
<tr>
<td>1.67 Q</td>
<td>2020</td>
</tr>
</tbody>
</table>

A: 450V-2.9 μm  B: 450V-2.7 μm  C: 450V-2.4 μm  D: 500V-2.4 μm  E: 475V-2.2 μm
• Ripple current handling ability improvement

- Increase max. operation temperature from 105°C to 115 °C
- ESR improvement: Metallization layer design optimize; Narrow metallization film design.
- Thermal conductivity improvement of potting material
- Special cooling structure design
- Optimize thermal performance via simulation result
• Lower ESL for higher frequency application

Typical value:
~2015: 10~15nH
2016~2020: 5~10nH
2021~: ≤5nH

- Lamination busbar optimization
- Low ESL terminal design
- Low ESL internal connection design

ESR curves at different terminal design

ESL measurement
• Roadmap for high temperature DC Link film capacitor

<table>
<thead>
<tr>
<th></th>
<th>Time</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hotspot temp.</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>PEN-HV</td>
<td>125 °C</td>
<td>Samples</td>
<td>Pilot products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other H.T. materials</td>
<td>140 °C</td>
<td>Film application researching</td>
<td>Samples</td>
<td>Pilot products</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Target: Higher temperature!

Sample introduction:
DC-Link Film capacitor for EV/HEV power electronics at 125°C.

Properties:
- High heat resistance\[ continuously 125 °C, short time 150 °C \].
- Higher allowable ripple current under higher temperature environment than PP film capacitor(105 °C).
- High frequency range.
Thank You
Faratronic, your trusty partner
APEC Booth 1156

Faratronic Contact China
Chris Zhuang
M: +86-13606018583
chris@Faratronic.com.cn
www.Faratronic.com

Faratronic Contact USA
Michael Dombrow
M: 847-212-2413
mc@dombrowinc.com